INTEGRATING CO_2-EOR AND CO_2 STORAGE IN OIL RESERVOIRS

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Prepared by:

Vello A. Kuuskraa (vkuuskraa@adv-res.com)
Advanced Resources International, Inc.

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PRESENTATION OUTLINE

1. DOE Basin Studies
2. "Next Generation" CO_2-EOR
3. Integrating CO_2-EOR and CO_2 Storage
4. Summary

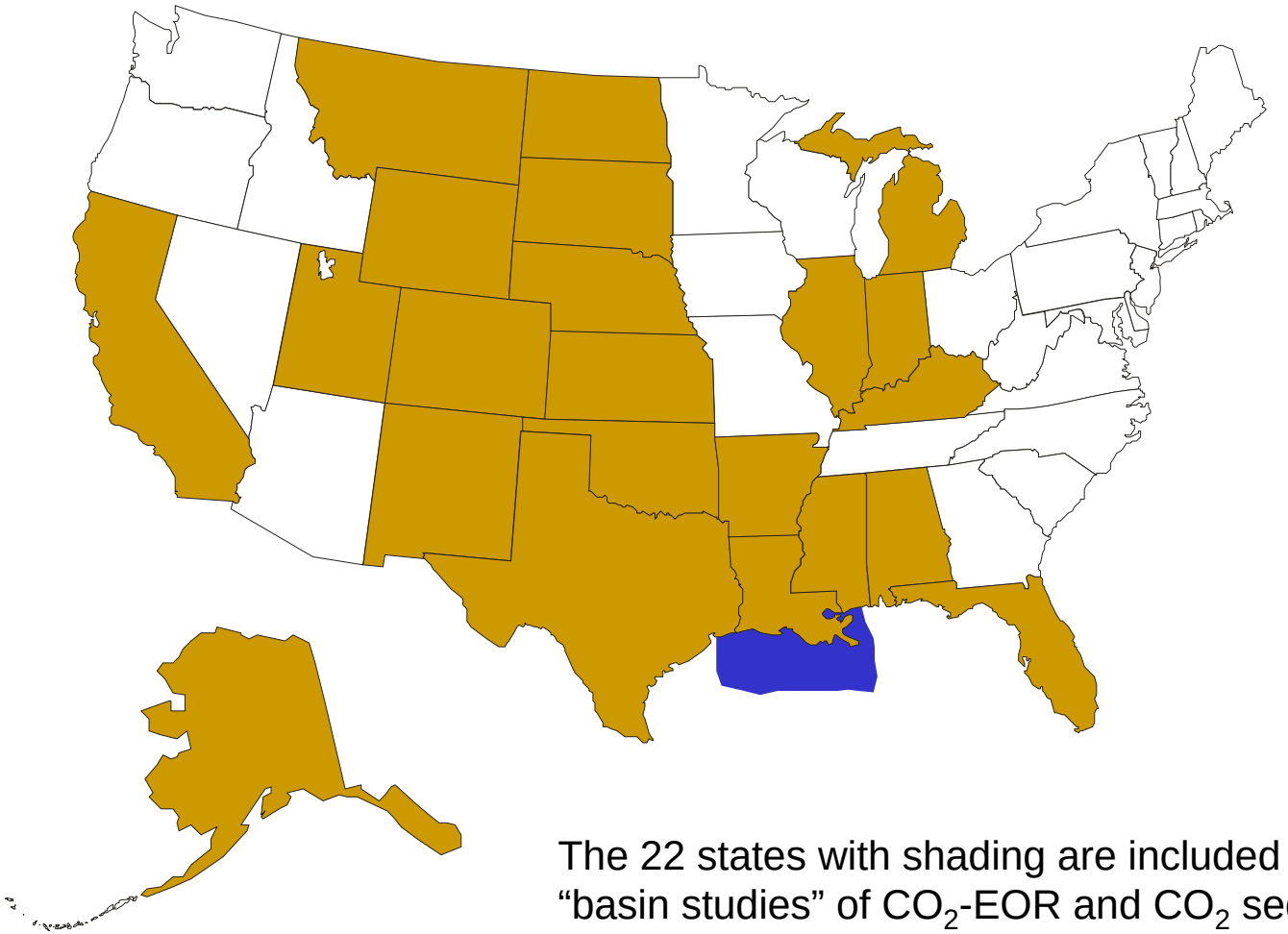
1. DOE BASIN STUDIES: CO_2-EOR AND CO_2 STORAGE

Our company, Advanced Resources, recently completed a series of ten "basin studies" for DOE that address CO_2-EOR and CO_2 storage.

- Cover 22 of the oil producing states plus offshore Louisiana (shelf),
- Include 1,581 large (>50 MMBbls OOIP) oil reservoirs (two thirds of U.S. oil production),
- Estimate oil recovery and CO_2 storage using streamline reservoir simulation,
- Calculate economics using "industry standard" cash flow.

These reports are available on the U.S. Department of Energy's web site at http://www.fe.doe.gov/programs/oilgas/eor/Ten_Basin-Oriented_CO2-EOR_Assessments.html

U.S. BASINS/REGIONS STUDIED FOR FUTURE OIL RECOVERY AND CO_2 SEQUESTRATION POTENTIAL FROM CO_2-EOR



The 22 states with shading are included in the ten "basin studies" of CO_2-EOR and CO_2 sequestration.

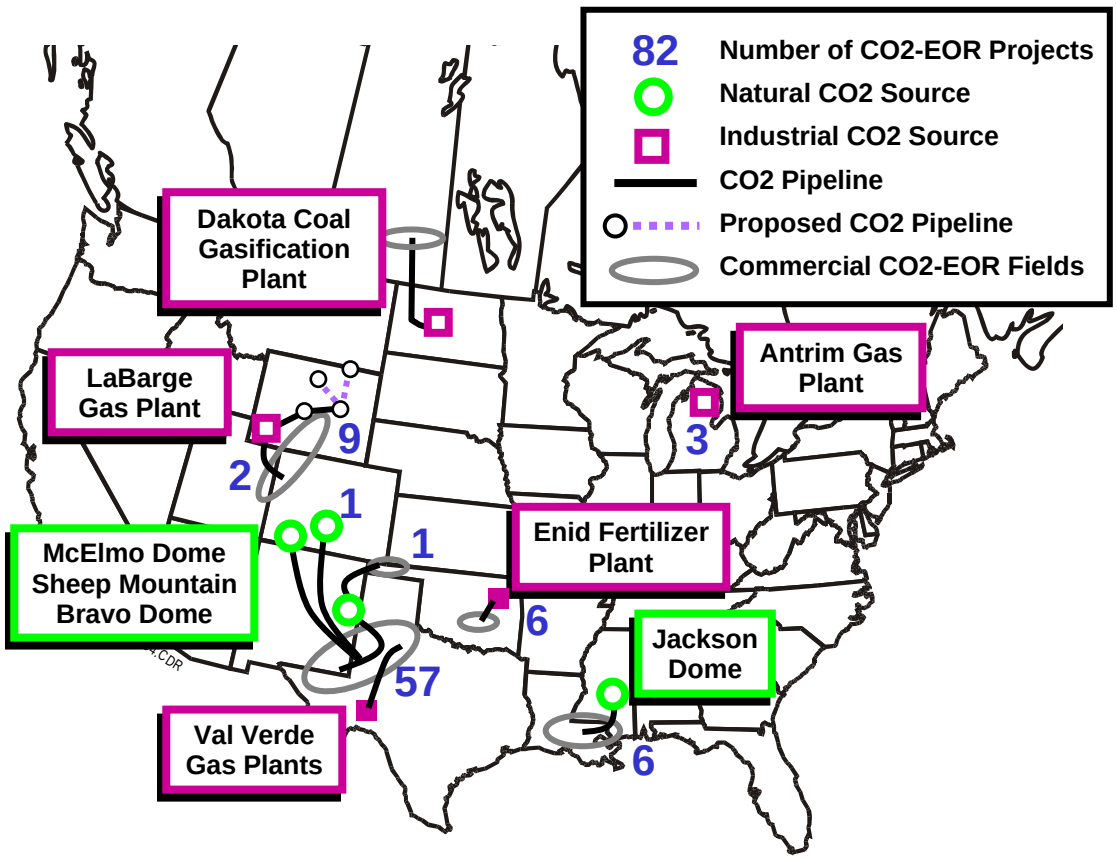
DOE BASIN STUDIES: MEETING THE CONGRESSIONAL MANDATE

The Congressional Budget language for FY2004 and FY2005 directed that "basin-oriented" assessments be conducted to "examine new steps to accelerate adoption of carbon dioxide-based enhanced oil recovery".

The Congressional Budget language for FY2006 added emphasis on "productively using industrial sources of CO_2."

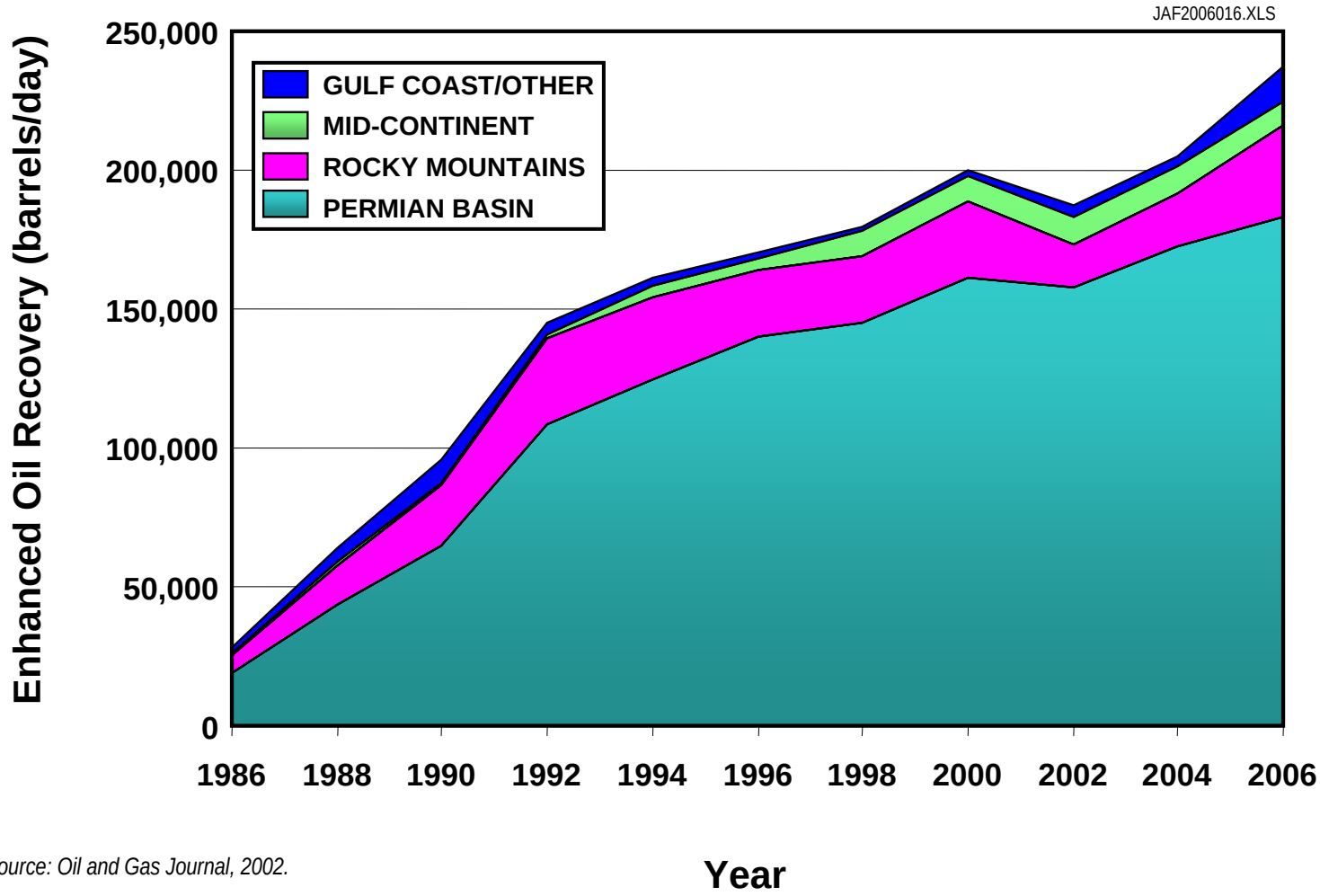
One DOE/FE step toward meeting this Congressional mandate has been to prepare a series of technical reports.

DOMESTIC CO_2-EOR ACTIVITY



- Currently, 82 CO_2-EOR projects provide 237,000 B/D of production
- Affordable natural CO_2 launched CO_2-EOR activity in the 1980's
- Federal tax credits (Sec.43) and state severance tax relief still encourage CO_2-EOR
- New CO_2-EOR players:
  - OxyPermian (purchased Altura; adding new CO_2-EOR projects)
  - KinderMorgan (providing CO_2 pipelines/supply; purchasing oil fields amenable to CO_2-EOR)
  - Denbury (using Jackson Dome CO_2 for EOR in Mississippi and Louisiana)
  - Anadarko (using CO_2 from the LaBarge gas processing plant for EOR in the Rockies)

GROWTH OF CO_2-EOR PRODUCTION IN THE U.S.



Source: Oil and Gas Journal, 2002.

VOLUMES OF CO_2 INJECTED FOR EOR

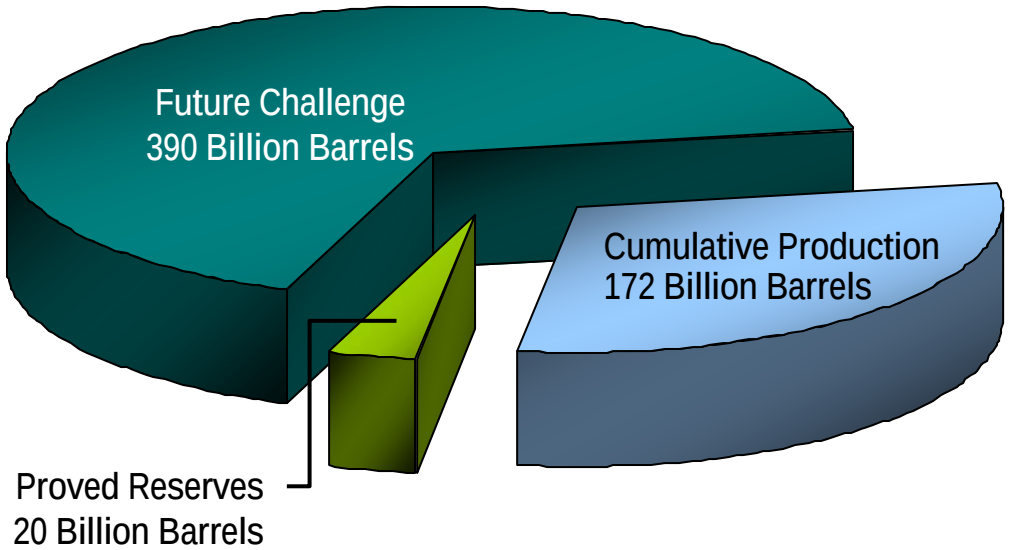
State/ Province (storage location)	Source Type (location)	CO_2 Supply MMcfd	
		Geologic	Anthropogenic*
Texas-Utah-New Mexico	Geologic (Colorado-New Mexico) Gas Processing (Texas)	1,400	110
Colorado-Wyoming	Gas Processing (Wyoming)	0	240
Mississippi	Geologic (Mississippi)	100	0
Michigan	Ammonia Plant (Michigan)	0	2
Oklahoma	Fertilizer Plant (Oklahoma)	0	35
Saskatchewan	Coal Gasification (North Dakota)	0	145
TOTAL		1,500	532

**Source: Advanced Resources International, 2004*

LARGE VOLUMES OF DOMESTIC OIL REMAIN "STRANDED" AFTER PRIMARY/SECONDARY OIL RECOVERY

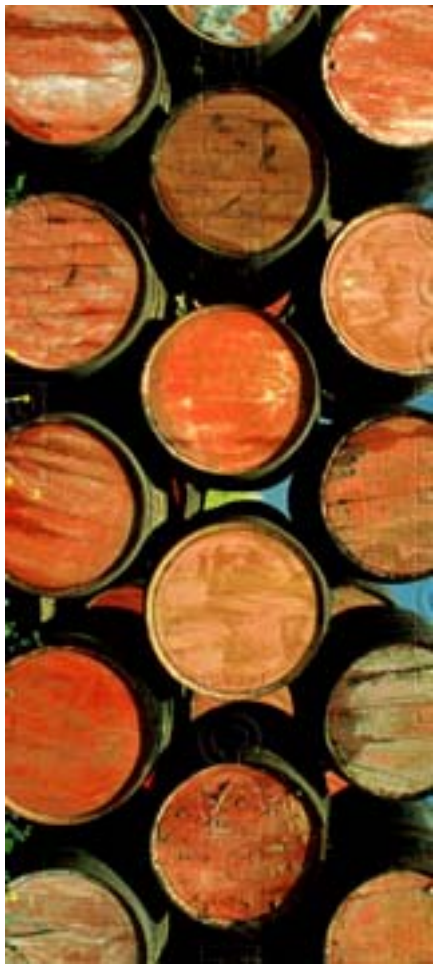
Original Oil In-Place: 582 B Barrels*

"Stranded" Oil In-Place: 390 B Barrels*



*All domestic basins except the Appalachian Basin.
Source: Advanced Resources Int'l. (2005)

BASIN STUDIES: TECHNICALLY RECOVERABLE



Nearly 89 billion barrels could become technically recoverable, providing a market for 20 billion metric tons of "EOR-Ready" CO_2.

The economically recoverable portion depends on: (1) the "oil price" and market risk premium used for CO_2-EOR investment decisions; (2) significant demonstrations of "state-of-the-art" CO_2-EOR technologies to lower technical risk; and, (3) access to sufficient, low cost "EOR-Ready" CO_2 supplies.

TECHNICALLY RECOVERABLE RESOURCES: "STATE-OF-THE-ART" CO_2-EOR (TEN BASINS/AREAS)

Basin/Area	DATABASE			ALL RESERVOIRS		
	Large Reservoirs					
	# of Reservoirs	% of Resource	# Favorable For CO_2-EOR	OOIP* (Billion Barrels)	ROIP** (Billion Barrels)	Technically Recoverable (Billion Barrels)
1. Alaska	34	97%	32	67.3	45.0	12.4
2. California	172	90%	88	83.3	57.3	5.2
3. Gulf Coast	239	60%	158	44.4	27.5	6.9
4. Mid-Continent	222	59%	97	89.6	65.6	11.8
5. Illinois/Michigan	154	61%	72	17.8	11.5	1.5
6. Permian	207	74%	182	95.4	61.7	20.8
7. Rockies	162	68%	92	33.6	22.6	4.2
8. Texas, East/Central	199	65%	161	109	73.6	17.3
9. Williston	93	72%	54	13.2	9.4	2.7
10. Louisiana Offshore	99	80%	99	28.1	15.7	5.9
Total	**1,581**		**1,035**	**581.7**	**390.0**	**88.7**

*Original Oil in Place, in all reservoirs in basin/area; ** Remaining Oil in Place, in all reservoirs in basin/area.
Source: Advanced Resources Int'l, 2006.

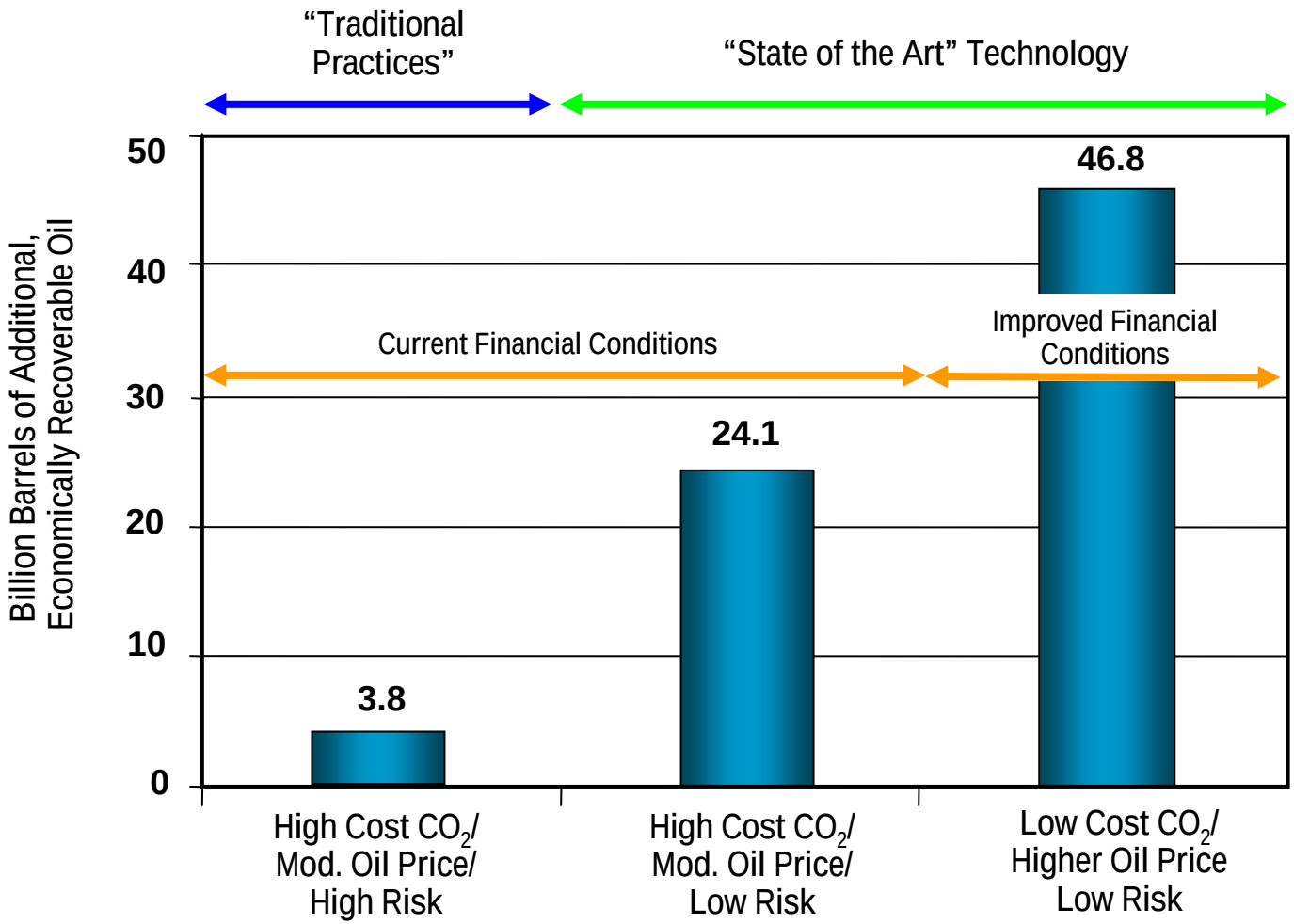
BASIN STUDIES: ECONOMICALLY RECOVERABLE OIL

From 4 to 47 billion barrels of domestic resource could be economically added to domestic oil supply with CO_2-EOR technology.

- "*Traditionally practiced*" CO_2-EOR technology (small volumes of CO_2, high technical risks) would enable only a modest portion, 4 billion barrels, of this CO_2-EOR potential to be economic.[1]
- "*State-of-the-art*" CO_2-EOR technology (larger volumes of CO_2, modified injection design) plus lower technical and economic risks would make 24 billion barrels economically viable.[2]
- Availability of lower cost, "*EOR-Ready*" CO_2 supplies would increase the economically viable resource to nearly 47 billion barrels and accelerate the conversion of this resource to reserves and production.[3]

1. This case assumes an oil price of $30 per barrel, a CO_2 cost of $1.20 to $1.50/Mcf, and a ROR hurdle rate of 25% (before tax).
2. This case assumes an oil price of $30 per barrel, a CO_2 cost of $1.20 to $1.50/Mcf, and a ROR hurdle rate of 15% (before tax).
3. This case assumes an oil price of $40 per barrel, a CO_2 cost of $0.80/Mcf, and a ROR hurdle rate of 15% (before tax).

ECONOMICALLY RECOVERABLE RESOURCES FROM CO_2-EOR



BASIN STUDIES: MARKET FOR PURCHASED CO_2

The current U.S. market for "EOR-Ready" CO_2 is on the order of 10 to 20 billion metric tons of CO_2. About 80% of this would become stored as part of CO_2-EOR.

Currently known natural CO_2 sources hold only about 2 billion metric tons; CO_2-EOR offers a major market for industrial CO_2.

	Recoverable Oil	Purchased CO_2		Stored CO_2
	(Billion Barrels)	(Tcf)	(Billion Tonnes)	(Billion Tonnes)
Technically Recoverable	89	377	20	16
Economically Recoverable*	47	188	10	8

* $40 per bbl oil price, CO_2 cost of $0.80/Mcf, ROR of 15% before tax.

BASIN STUDIES: MARKET FOR PURCHASED CO_2
(TEN BASINS/AREAS)

Basin/Area	Technically Recoverable (Billion Barrels)	Purchased CO_2 (Tcf)
1. Alaska	12.4	51.4
2. California	5.2	23.9
3. Gulf Coast	6.9	33.3
4. Mid-Continent	11.8	36.3
5. Illinois/Michigan	1.5	5.7
6. Permian	20.8	95.1
7. Rockies	4.2	27.5
8. Texas, East/Central	17.3	62.0
9. Williston	2.7	10.8
10. Louisiana Offshore (Shelf)	5.9	31.0
Total	**88.7**	**377.1**

Source: Advanced Resources Int'l, 2006.

2. "NEXT GENERATION" CO_2-EOR TECHNOLOGY

Reservoir modeling and selected field tests show that high oil recovery efficiencies are possible using innovative applications of CO_2-EOR.

Under ideal conditions, gravity-stable laboratory core floods have recovered essentially all of the residual oil.

Using horizontal wells (and other process designs) that facilitate contact of the reservoir's pore volume with CO_2 would make high oil recovery efficiencies possible.

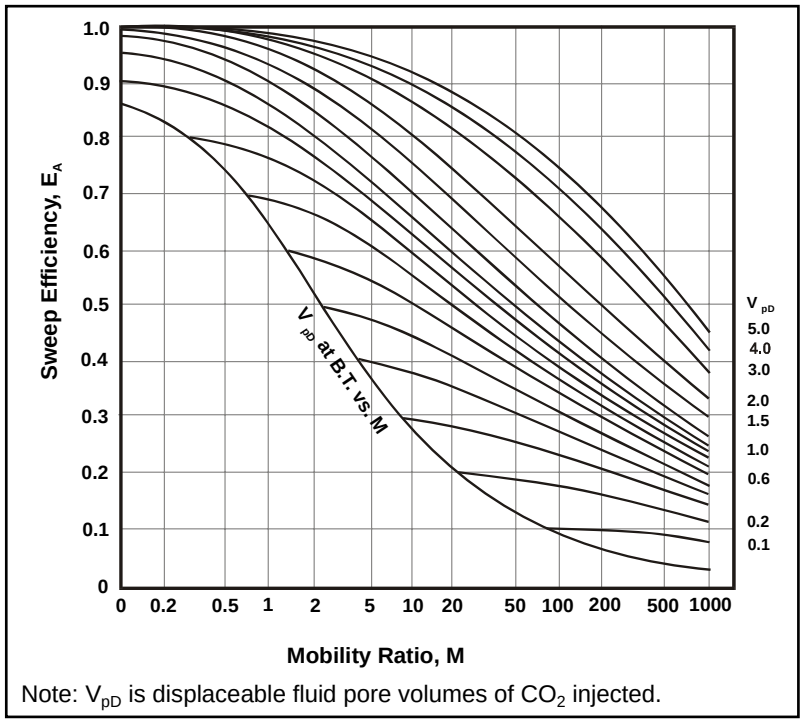
So far, except for a handful of cases, the actual performance of CO_2-EOR in the field has been less than optimum, hampered by:

- **Geologically complex reservoir settings**
- **Lack of "real time" performance information**
- **Limited process control capacity**

LIMITATIONS OF PAST PERFORMANCE

Because of high CO_2 costs and lack of information and process control, the great majority of past-CO_2 floods have used insufficient volumes of CO_2.

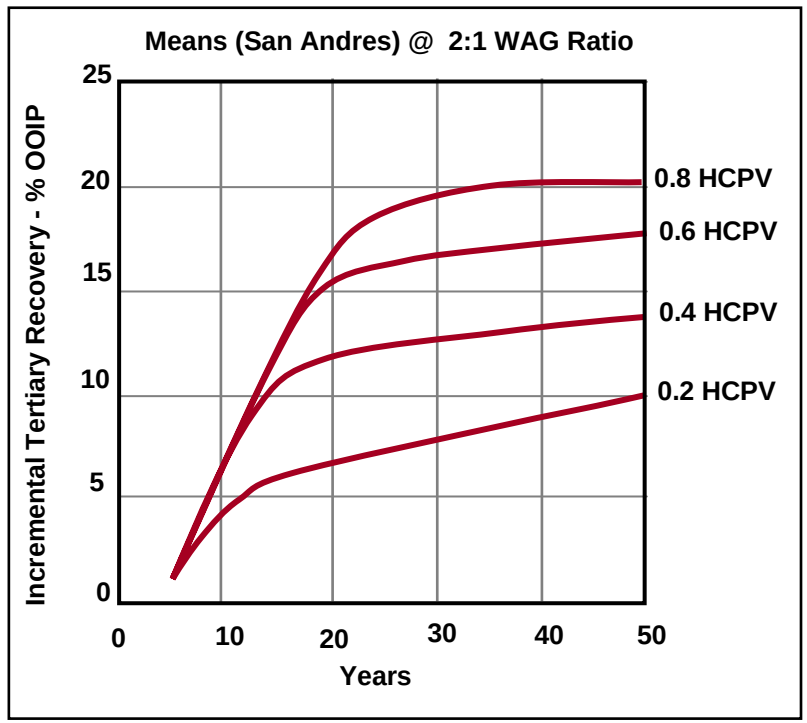
Sweep Efficiency in Miscible Flooding



Note: V_{pD} is displaceable fluid pore volumes of CO_2 injected.

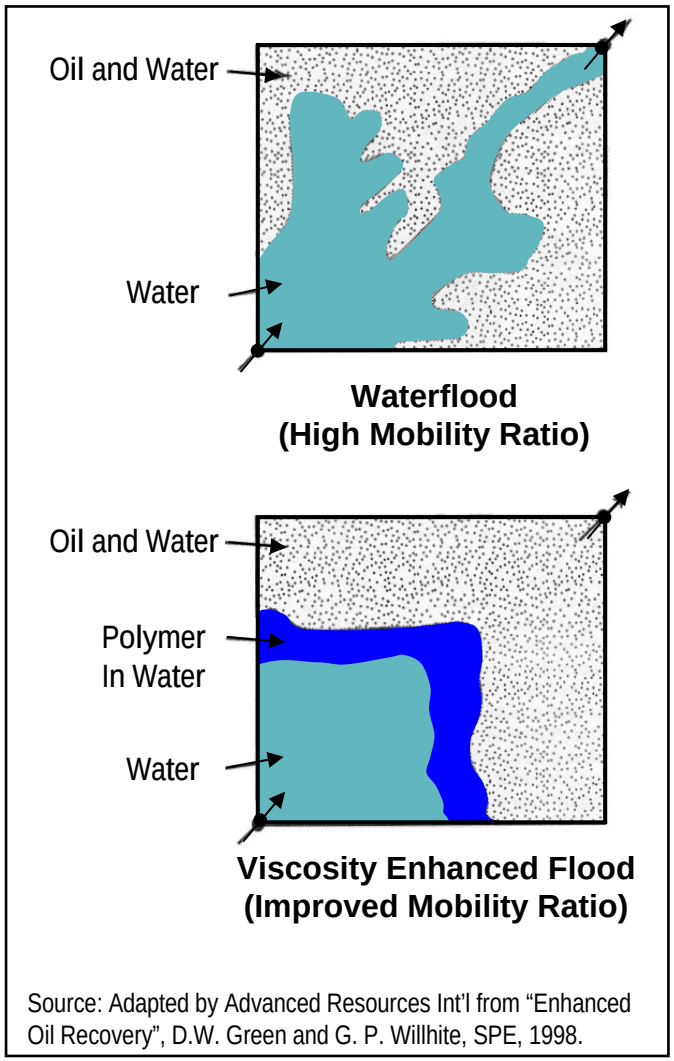
Source: Claridge, E.L., "Prediction of Recovery in Unstable Miscible Displacement", SPE (April 1972).

Injected CO_2 vs Oil Recovery



Source: SPE 24928 (1992)

LIMITATIONS OF PAST PERFORMANCE

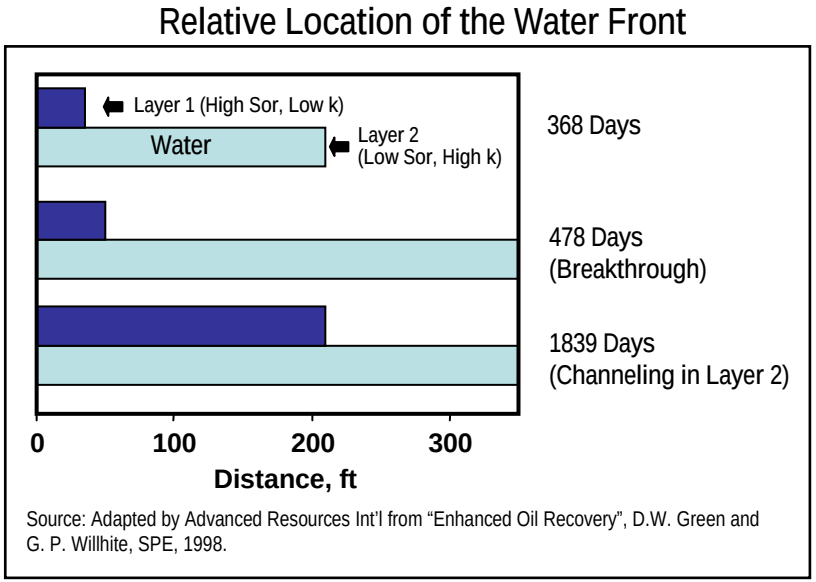


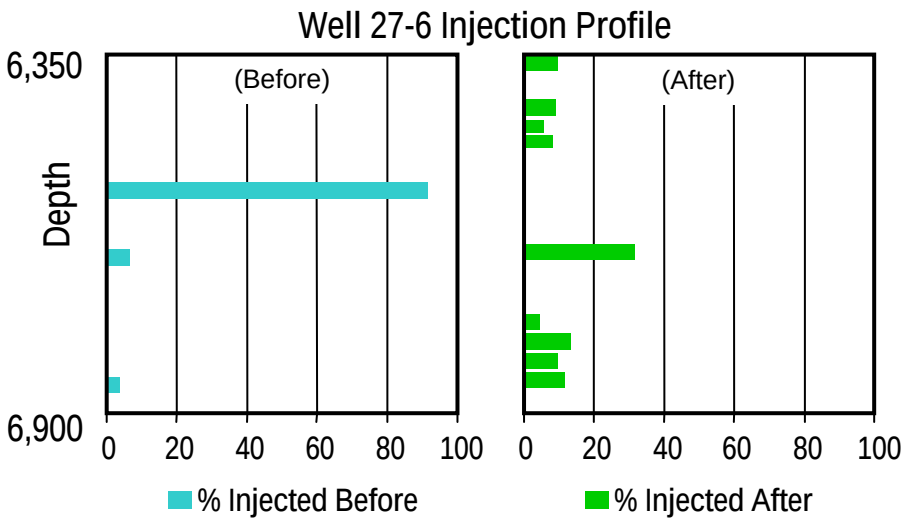
In many of the previous CO_2 floods, the injected CO_2 achieved only limited contact with the reservoir:

- **Viscous fingering**
- **Gravity override**

The figure shows how addition of viscosity enhancers could help improve reservoir contact.

REVIEW OF PAST PERFORMANCE





A major barrier is the inability to target the injected CO_2 to reservoir strata with high residual oil saturation.

The figures show: (1) the higher oil saturation and lower permeability portion of the reservoir is inefficiently swept; and (2) CO_2 channeling can be mitigated with well workover.

3. INTEGRATING CO_2-EOR AND CO_2 STORAGE

The volumes of CO_2 purchased for (and stored by) CO_2-EOR in the ten "basin studies", assume:

- The primary objective is enhancing economic oil recovery (minimizing costs while optimizing oil production).
- No economic value or benefit is placed on "permanently" storing CO_2.
- CO_2-EOR is applied as the tertiary (third) oil recovery option.

As such, the above CO_2 requirements and storage volumes represent a minimum. The question is - - *How and by how much could this minimum volume be expanded?*

3. INTEGRATING CO_2-EOR AND CO_2 STORAGE (Cont'd)

Expanding CO_2 Storage Capacity: A Case Study. We use as the example a large Gulf Coast oil reservoir, with 340 million barrels (OOIP) in the main pay zone (above the producing oil-water contact).

This reservoir holds another 100 million barrels (OIP) in the underlying 130 feet of transition/residual oil zone and has an underlying saline reservoir 195 feet thick (within the spill point).

- Main Pay Zone:
  - Depth - - 14,000 feet
  - Oil Gravity - - 33°API
  - Porosity - - 29%
  - Net Pay - - 325 feet
  - Initial Pressure - - 6,620 psi
  - Miscibility Pressure - - 3,250 psi
- Primary/Secondary Oil Recovery: 153 million barrels (45% of OOIP, in MPZ)

This reservoir has 2,710 Bcf (143 million tonnes) of theoretical CO_2 storage capacity.

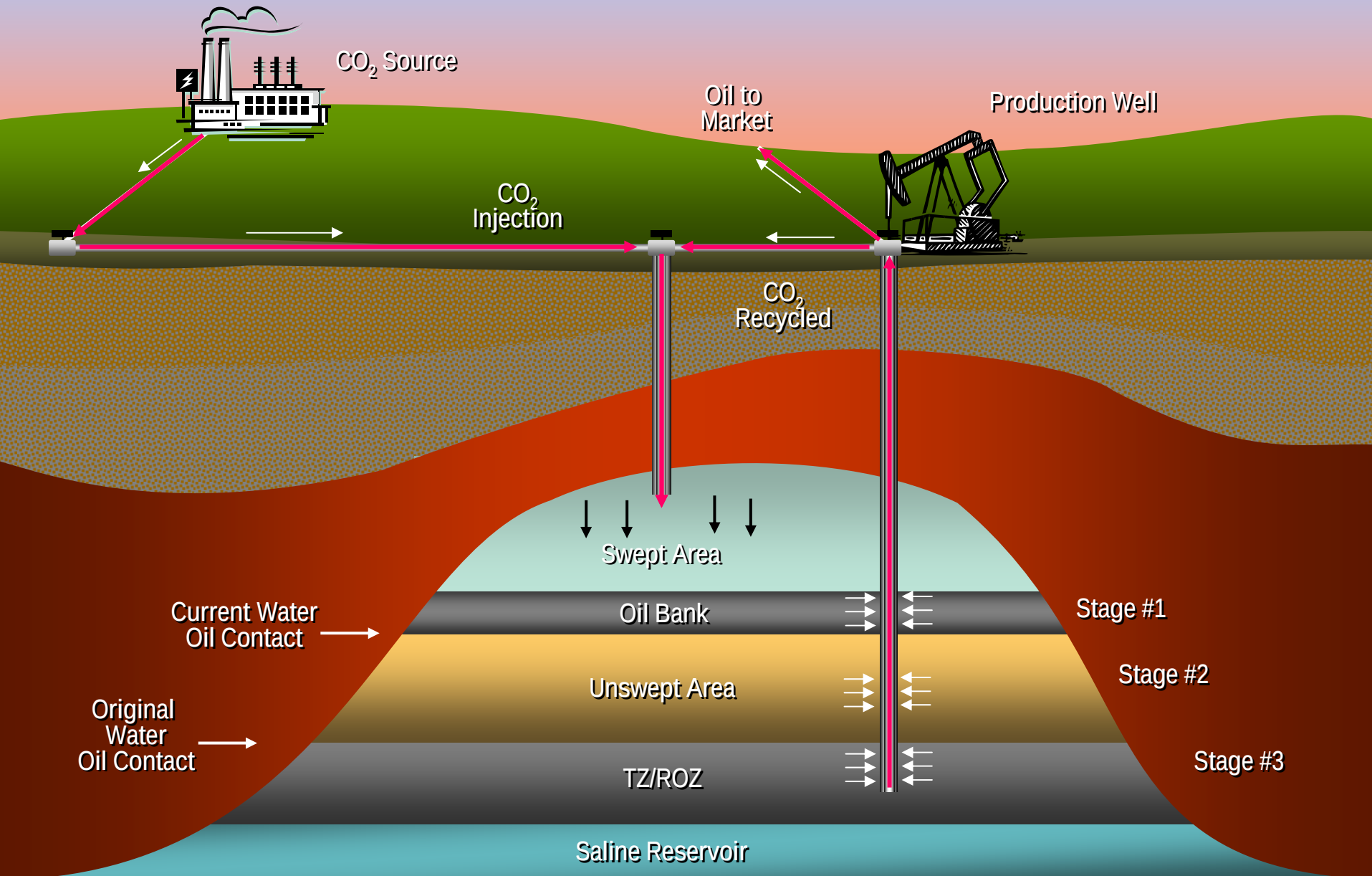
3. INTEGRATING CO_2-EOR AND CO_2 STORAGE (Cont'd)

State-of-the-Art. First, this Gulf Coast oil reservoir is produced using "state-of-the-art" CO_2-EOR project design - - vertical wells, 1 HCPV of CO_2 (purchased and recycled CO_2), and a 1:1 WAG.

"Next Generation". Next, this Gulf Coast oil reservoir is produced using "next generation" CO_2-storage and CO_2-EOR project design.

- Gravity-stable, vertical CO_2 injection with horizontal production wells.
- Targeting the main pay zone, plus the transition/residual oil zone and the underlying saline reservoir.
- Injecting continuous CO_2 (no water) and continuing to inject CO_2 after completion of oil recovery.
- Instituting a rigorous diagnostic and monitoring effort.

3. INTEGRATING CO_2-EOR AND CO_2 STORAGE (Cont'd)



3. INTEGRATING CO_2-EOR AND CO_2 STORAGE (Cont'd)

With "next generation" CO_2 storage and EOR design, much more CO_2 can be stored and more oil becomes potentially recoverable.

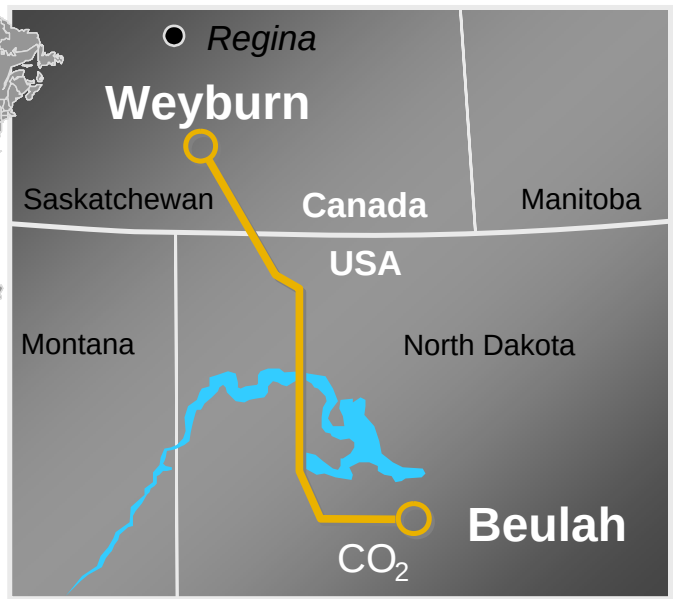
Importantly, the additional oil produced by "next generation" technology is "GREEN OIL".

	"State of the Art"	"Next Generation"
	(millions)	(millions)
CO_2 Storage (tonnes)	19	109
Storage Capacity Utilization	13%	76%
Oil Recovery (barrels)	64	180
% Carbon Neutral ("Green Oil")	80%	160%

However, considerable additional work is required to build this "next generation" technology and knowledge base for advanced CO_2-EOR and CO_2 storage.

Weyburn Enhanced Oil Recovery Project

(An Operating Project Maximizing Oil Recovery and CO_2 Storage)

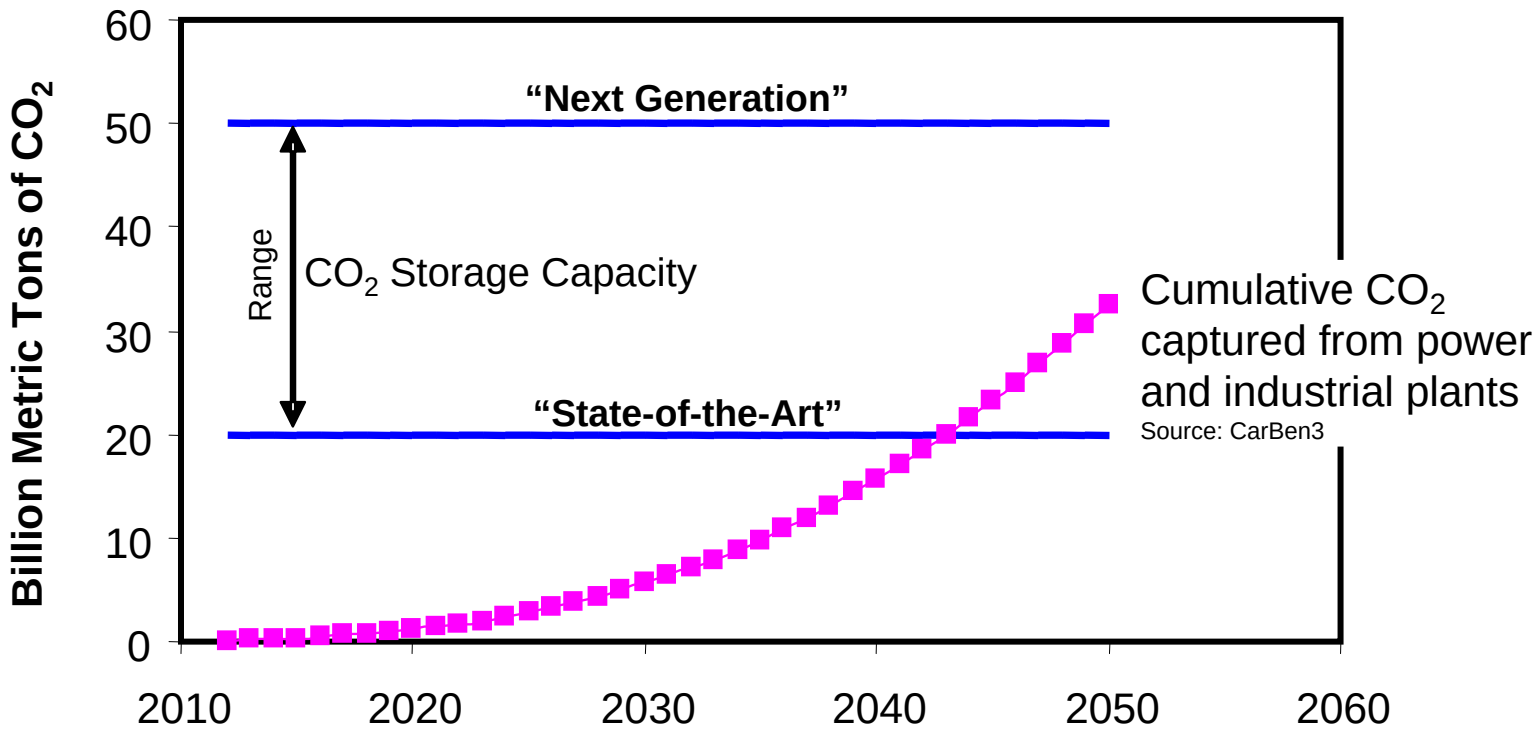


- Largest CO_2 EOR project in Canada:
  - OOIP 1.4 Bbbls
  - 155 Mbbls incremental
- Outstanding EOR response
- World's largest geological sequestration project
  - 2.4 MMt/year (current)
  - 7 MMt to date
  - 23 MMt with EOR
  - 55 MMt with EOR/sequestration

"NEXT GENERATION" CO_2-EOR AND CO_2 STORAGE

With advanced ("next generation") CO_2-EOR and CO_2 storage technologies, oil formations would have enough capacity to store much of the captured CO_2 in the near- to mid-term.

Regional considerations argue that all CO_2 storage options (oil & gas reservoirs, deep coal seams and saline formations) will be required.



SUMMARY

Oil reservoirs have numerous attributes that make them attractive for storing CO_2 - - an established, secure trap; “value-added” products; and, existing infrastructure.

With “next generation” technology, that integrates CO_2 storage and oil recovery, a much greater portion of the available CO_2 storage capacity in oil reservoirs will become useable.

Plans are to provide a more sophisticated inclusion of this work in the updated version of NEMS, ready for AEO 2008.

- Linkage to levels of R&D investment
- Advanced technology levers
- Integration with sources of CO_2.

Office Locations
Washington, DC
4501 Fairfax Drive, Suite 910
Arlington, VA 22203 USA
Phone: (703) 528-8420
Fax: (703) 528-0439

Houston, Texas
11490 Westheimer Road, Suite 520
Houston, TX 77077
Phone: (281) 558-9200
Fax: (281) 558 9202

Pittsburgh, Pennsylvania
401 Wood St. Suite 900
Pittsburgh PA 15222-1824 USA
Phone: (412) 281-6568
Fax: (412) 281-6747